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Rheological properties of liquid foods at elevated temperatures

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1.Introduction

For the UHT processing of liquid foods the tubular heat exchangers are used now with increased pressure to avoid the boiling of processed fluids at temperatures above 100°C. The design of such an equipment needs e.g. the knowledge of rheological properties, see e.g. Trifiro et al (1991). Mathematical modeling of this process recalls also the necessity of these data. Unfortunately, there is the shortage of this data for common fluid foods. The knowledge of reliable data is limited up to 80°C till now, see e.g. Fito et al (1983), Sestak et al (1998). The data above 100°C are not available, see review in thesis given by Luon Cam Thi (1996).

The goal of this work, therefore, was to develop reliable experimental set-up for measuring the rheological properties of fluid foods above 100°C and to measure the flow properties of tomato puree which is produced by UHT process on an aseptic line TetraLaval Ltd., at temperature 125°C in the broadest ranges of shear rates and temperatures. The second aim of this study was to predict the temperature dependence of viscosity of commercial sunflower oil.

2.Material and methods

Description of instrument and procedure

Schema of the experimental set-up is shown on Fig.1. The apparatus consists of commercial rheometer Haake RV3 (with coaxial cylinders) which was covered with pressure vessel. This vessel is equipped with thermostatic bath and cooling bath and is isolated with polyurethane foam thermal insulation. The thermostat UH4 Medingen (Germany) was filled with silicone oil (Chemical works Kolín, CR). Vessel was pressurized with compressed air. The cavern between rheometer and vessel was filled with silicagel and deformed aluminium film to condense and bound water vapor coming from the sample during heating. This action together with providing the small airflow through the leakage in decompression valve enables to protect the inner sensitive parts of the rheometer (motor, tachodynamo and torque measuring unit).

The actual temperature of the sample of studied fluid was measured by using the thermocouple placed in annular shell of the inner cylinder filled with mixture of measured fluid and vegetable oil placed here to avoid the loss of water from the sample.

Measured sample was placed into the cup and inner cylinder was mounted into the rheometer. Then the cup was pushed into the rheometer. After that the covering oil was filled onto the upper surface of the sample (through the side opening in the pressure vessel) to fill the upper shell of the inner cylinder and create about 5 mm thick layer above the sample, see Fig.1. The vegetable oil was used being unmiscible with the sample. Then the vessel was closed and pressurized with compressed air and overpressure 2.1 bar was maintained as a minimum. The rotational speed was then selected and the heating of circulated oil started. The torque as a function of temperature for constant rotational speed was measured. The procedure was repeated for different rotational speeds. Before each run the instrument was cooled down and new sample was introduced into the gap of the rheometer. The torque was then recalculated to shear stress or apparent viscosity, rotational speed was recalculated to shear rate. The flow curves (apparent viscosity as a function of shear rates) were constructed for data read for the same temperature. If it was not possible to construct these flow curves instantaneous flow curves were measured by quick changing of rotational speed and reading the torque. This procedure was done at the end of heating procedure only.

Samples description

Tomato purée Mikulka, internal standard PN 01001/95, product of Cooperative farm Mikulčice, CR, was measured as a first sample. This product was UHT sterilized and aseptically filled into 200 ml paper boxes. Composition of this product was: tomato concentrate, water, sugar, starch and salt. The shear stress as a function of temperature during reheating for constant shear rate was measured. This procedure was repeated for different shear rates with new filling of the rheometer. The data for flow curves were then selected for the same temperature. Apparent viscosity as a function of shear rates and temperature resulted from these data sets.

The second sample, semiproduct for preparing tomato purée Mikulka, was measured. The components were mixed carefully together and semiproduct was cooked directly in the rheometer during heating to 127°C for preselected constant rotational speed (shear rate). The procedure was repeated for different rotational speeds and for each run the new sample was filled into the gap of the rheometer. This measuring procedure mimics the industrial process of cooking the starch having the strong effect on the final product texture. The premix consisted of 38.6% of tomato concentrate (refractive dry matter 26%), 2% sucrose, 0.4% salt, 57% water and 2% of starch. The starch was mixed into the cold water and other ingredients added. Before and after the rheological experiment the refractive dry matter was measured using Zeiss (Germany) refractometer.

The third sample was commercial vegetable sunflower oil Lukana, product of Milo Olomouc, Joint stock Co.,internal standard PN140802. We have measured the viscosity of this sample as a function of temperature for four shear rates. Newtonian flow behaviour was identified before measurement of temperature dependence.

3.Results and discussion

Experimentally predicted time-temperature history during heating of tomato purée Mikulka in rheometer is shown in Fig.2. The mean heating rate during temperature rise from 30 to 123°C for 24 minutes has value 3.9°C per minute. The maximum heating rate was achieved between 10 and 15 minute having the value 6.5°C per minute. This temperature history was typical for tomato purée, ultrathermostat used and loss of heat of the apparatus.

The flow curves of the final product, tomato purée Mikulka, reheated in the rheometer are shown in Fig.3. It is apparent from this figure that the product behaves as pseudoplastic power-law fluid which consistency coefficient K′ decreases monotonically with increasing temperature but its flow behaviour index seems to be constant. The power law

$$\mu = K'.\dot{\gamma}^{n-1} \qquad (1)$$

was used for data regression and resulting parameters K′and n are shown in Table I. The mean value n = 0.34. Coefficient of consistency was related to temperature and resulting dependence for apparent viscosity was predicted (T=30-125°C, shear rate 2.5 - 120 s^{-1})

$$\mu = 7.47\exp(-0.0113.T).\dot{\gamma}^{-0.66} \qquad (2)$$

This simple behaviour is probably related to the very well cooled starch and developing fully its ability to thicken the product.

Much more complicated behaviour was found for tomato purée semiproduct cooked in rheometer. The Fig.4 shows that great change of apparent viscosity occurs between 55 and 65°C. Above 65°C the further decay of viscosity is observed. The greatest changes of viscosity are apparent for the lowest shear rates. The viscosity increase is connected with starch granules swelling and cooking. The mechanical treatment of shear rates plays also the role in starch cooking. This non-linear effect disabled to construct the flow curves for selected temperatures read from data measured for different shear rates (rotational speeds). Therefore, the instantaneous flow curves were measured at the end of each measuring run (at temperature 127°C) by quick changing the rotational speeds. The results of this type of measurements are shown in Fig.5 and evaluated parameters are given in Table II. As follows from this data the flow curves measured at 127°C depend not only on temperature history and shear rate during heating but also on final dry matter. The changes of the dry matter should be taken into account, see Table III. These changes were detected in spite of the covering the surface of the sample by sunflower oil. The maximum dry matter difference was found to be up to 3%.

The Fig.5 shows that nearly all the flow curves received exhibit the same flow behaviour index n, see also Table II. By comparison Fig.3 and Fig.5 it is possible to find that the flow behaviour index of both samples is nearly the same (compare also the data from Tab.I and II). If we compare the whole flow curves we can find that the flow curve of the final product (valid for 125°C) is nearly the same as flow curve of semiproduct cooked at shear rate 105.77 s^{-1}. The increase of apparent viscosity during cooking of semiproduct should be taken into account for design of tubular heat exchangers and pumping systems used for processing of this product.

All the measured experimental values of viscosity of sunflower oil as a function of temperature are given in Fig.6. It is apparent that relatively big differences in viscosities were received for different shear rates applied for individual measurement run. Experimental data were represented by mathematical expression

$$\mu = 2.526.T^{-1.2562} \qquad (3),$$

for which the correlation coefficient 0.9996 was predicted. It is apparent that the viscosity decreases from value 0.035 Pa.s (valid for 30°C) up to value 0.006 Pa.s (for 125°C).

4.Conclusions

Results received with pressurized rheometer show that the experimental set-up can be used without greater problems for measuring of rheological properties of fluid foods in temperature range above 100°C.

Tomato purée Mikulka (reheated final product) behaves as typical power-law fluid with the flow behaviour index independent of temperature. The consistency coefficient strongly depends on the temperature. The resulting dependence of apparent viscosity on shear rate and temperature is given in equation (2).

Semiproduct for purée exhibited enormous increase of viscosity during heating between 55-65°C which should be taken into account during design of heating system for processing. After cooking the starch the product behaves by standard manner (viscosity decreases with increasing temperature). The flow curves of semiproduct measured at the end of cooking differ each other. This effect is caused probably by different shear history and loss of water.

The table sunflower oil is a Newtonian fluid which systematically decreases the viscosity with increasing temperature.

These results confirm that the experimental set-up gives the reproducible experimental data.

References

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Symbols

τ shear stress (Pa)

$\dot{\gamma}$ shear rate (s^{-1})

μ apparent viscosity (Pa.s)

K' consistency coefficient ($Pa.s^n$)

n flow behaviour index (-)

T temperature (°C)

Enclosures

Tab.I Rheological parameters of power-law model for reheated tomato purée Mikulka as a function of temperature

T (°C)	K´(Pa.s^n)	n (-)
30	5.30	0.34
49	4.19	0.33
78	3.28	0.33
125	1.79	0.37
mean	-	0.34

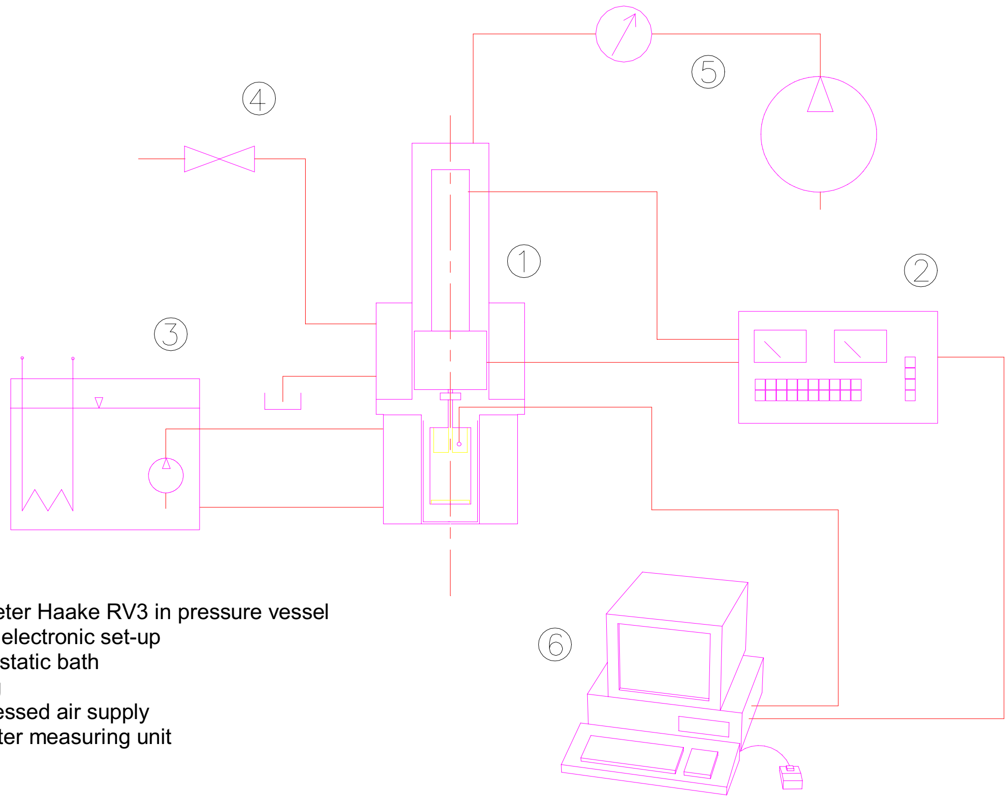
Tab.II Rheological parameters of tomato purée Mikulka as a function of shear rates during cooking in rheometer, measured at the end of experiment at temperature 127°C

$\dot{\gamma}$ (s^{-1})	K´(Pa.s^a)	n (-)
9.36	4.66	0.22
18.72	0.76	0.36
37.44	2.82	0.27
74.88	4.14	0.26
105.8	1.69	0.35
mean	-	0.29

Tab.III Changes of refractive dry matter during cooking of purée Mikulka in rheometer

$\dot{\gamma}$ (s^{-1})	R_p(%)	R_k(%)
9.36	11.5-12	14.0
18.72	11.5	14.5-15
37.44	12.8-13.0	13.5-13.9
74.88	not measured	11.5-12.1
105.8	11.5-12	14.5

Fig.1 Schema of experimental set-up



1 - rheometer Haake RV3 in pressure vessel
2 - Haake electronic set-up
3 - thermostatic bath
4 - cooling
5 - compressed air supply
6 - computer measuring unit

Fig.2 Temperature history of sample of tomato purée during heating, data for shear rate 37.44 s^{-1}

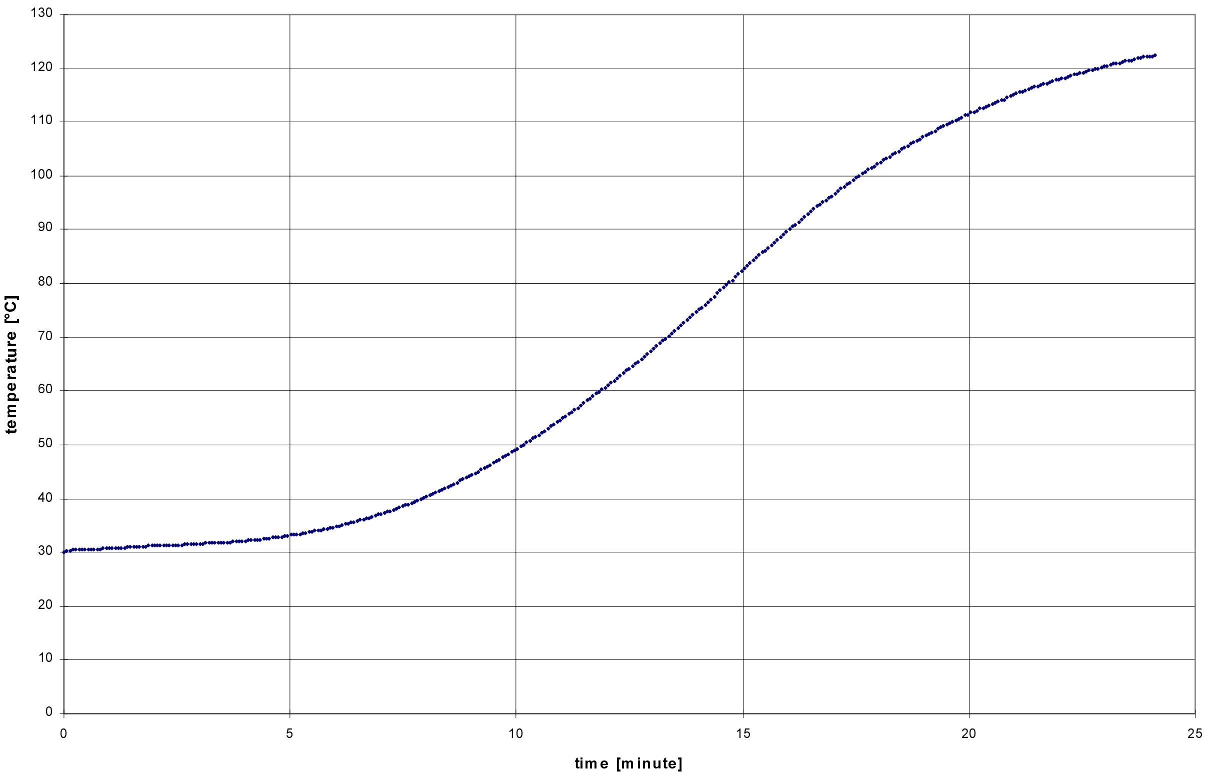


Fig.3 Tomato purée MIKULKA, measured under pressure 2.1 bar, reheated final product

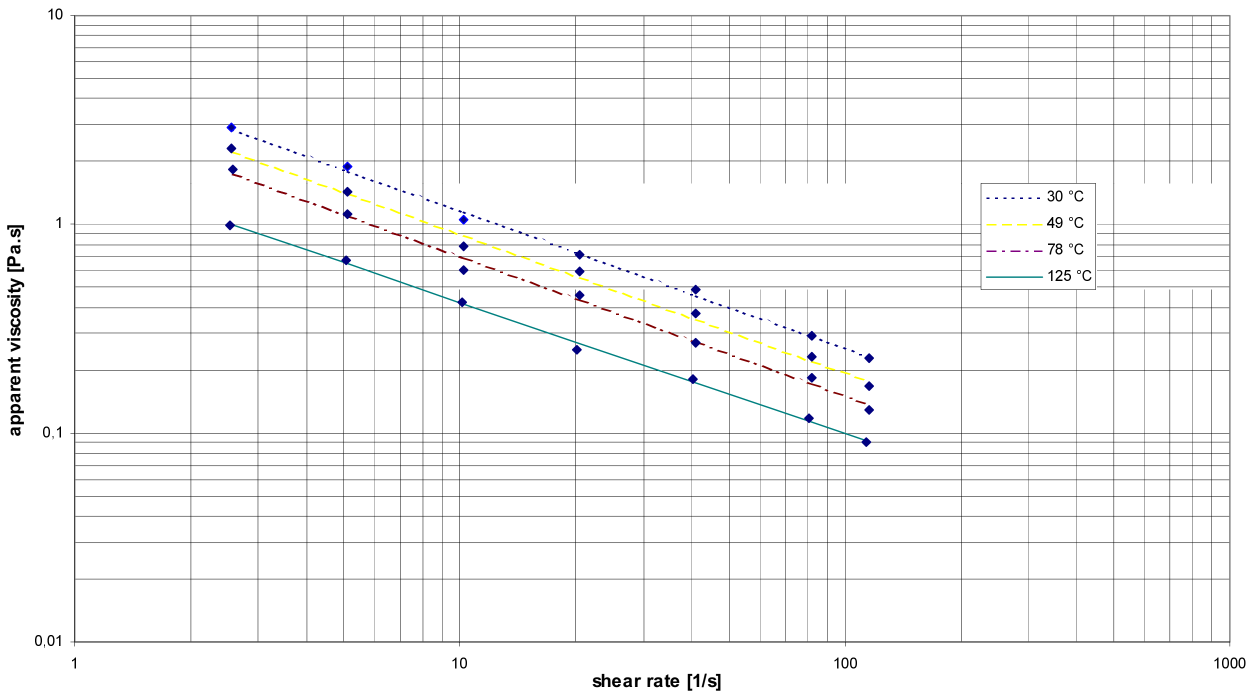


Fig.4 Apparent viscosity of tomato purée MIKULKA during cooking in rheometer at various shear rates

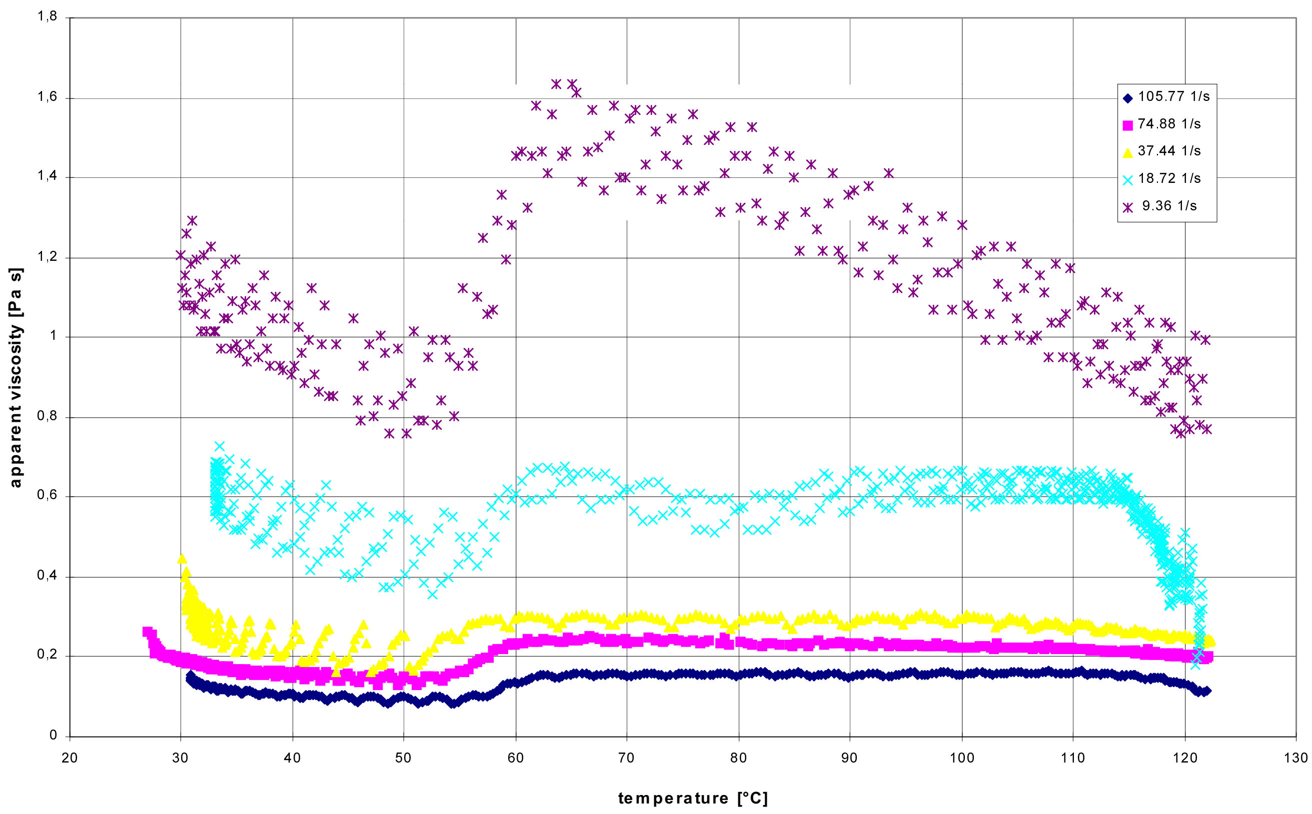


Fig.5 Apparent viscosity of tomato pureé MIKULKA at the end of cooking in rheometer for various shear rates of cooking - measured at actual state for final temperature 127°C

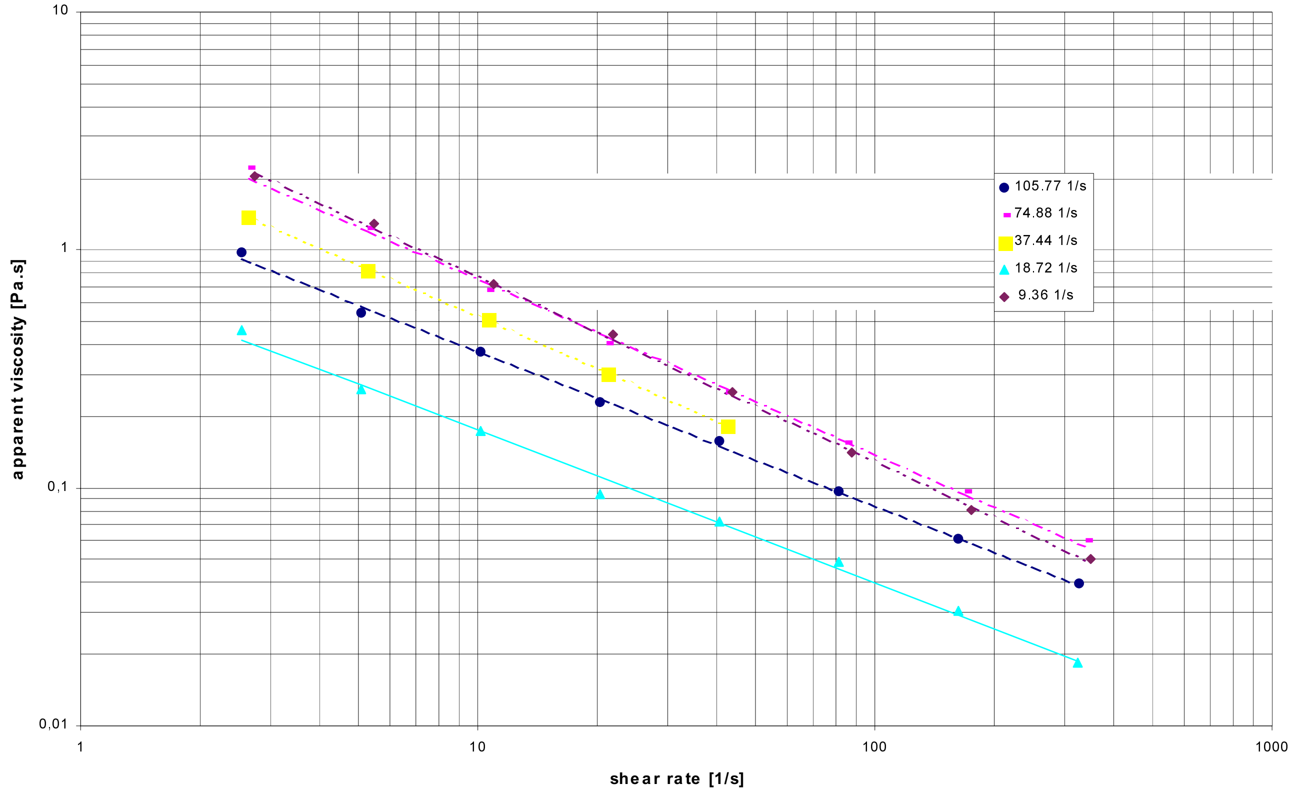


Fig.6 Dynamic viscosity of table sunflower oil LUKANA as a function of temperature